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IMPACT OF SIMULATION AS A PEDAGOGY IN STEM TEACHING AND LEARNING: A STUDY OF UNDERGRADUATE STUDENTS OF MUMBAI IN THREE STREAMS PHYSICS, ENGINEERING AND TECHNOLOGY

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ABSTRACT

Computer based interactive simulations are playing a very crucial role in today's education system. Due to the rapid increase in the advancement of technology and application oriented educational pattern, simulations are being used in the classrooms widely, particularly in the STEM (Science, Technology, Engineering, and Mathematics) subjects. However, the effectiveness of the simulations on students learning outcome at various levels has been a matter of interest for many researchers. The following study examines the significance of learning outcome in students pre and post use of simulation in the class room, the feedback from students as well as teachers on the use of simulation as a pedagogy, for better understanding and making them industry ready with 21st century required skill set. The study was conducted in three of the undergraduate programmes i) Bachelor of Science (B.Sc. Major Physics) ii) Bachelor of Science B.Sc. (IT) Information Technology iii) Engineering (B.E) from 3 of the top 10 institutions in Mumbai. 139 students 30 teachers participated in the survey. The result revealed that there is significant difference in the learning outcome of students when analyzed overall and Stream wise and gender wise. The study also compared the feedback of students with the teachers on the use of Simulation as a pedagogy in STEM Teaching and learning.

KEYWORDS: *Simulation, STEM, Pedagogy, Simulation Education, Learning Outcome*

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INTRODUCTION

Science, technology, engineering, and mathematics (STEM) students are required to work with sophisticated models of real-world systems. Whether these models are for infrastructure systems, communications networks, computer systems, or supply chains, surgical or health care system, STEM students require specialized instructions to make educated judgments that influence complex systems with thousands of variables and interactions among their components (Kutz et al. 2016). Furthermore, real-world systems are frequently susceptible to unpredictability and dynamism, some of which is induced by the human component (Gruler et al. 2019). These aspects cannot always be feasible to be incorporated in the traditional model of instruction that involves the physical set of a number of equipment involving high cost and also with proper safety concern.

Under such circumstances, the use of simulation software, tools, and games, as observed byJuan et al. (2017), helps the practical knowledge of these complex systems and allows students to enhance their learning experience through the implementation of hands-on activities appropriately planned by their instructors.

Simulation tool in Education can be considered as a very important lever or a catalyst in enhancing the application knowledge as it allows interaction and experimentation in different scenarios, enabling students to observe, analyze, experience, and test their conjectures putting into practice their theoretical knowledge. Simulation has the important characteristic of the recreation of an environment or model based on some behaviour of reality, or scientific or natural phenomena (D'Angelo et al., 2014; Psotka, 2013).

Teachers are being urged to use technology as a significant component of their teaching techniques as part of contemporary science efforts. The recent outbreak of Covid 19 which has disrupted teaching learning globally has made it a necessity in all fields more so in the STEM areas. Particularly in the STEM field use of technology can be considered as an educational tool in addition to being taking it as a topic in subject area. (Flick & Bell, 2000).

In the current study the impact of simulation as a pedagogy in few of the STEM areas is being studied.

LITERATURE REVIEW

Importance of Simulation

Simulation is the imitation of real-world system or process. Models are needed for simulations reflecting the key characteristics or behaviours of the chosen system or process, whereas the simulation shows the model's evolution across time. Simulations are frequently carried out on computers.

Simulation is utilized in a variety of settings, including technology simulation for performance tuning or optimization, safety engineering, testing, training, education, and video games. Simulation is also utilized alongside scientific modelling of natural systems or human systems to obtain insight into how they work. Simulation can be used to demonstrate the real-world consequences of certain conditions and actions. When the real system cannot be utilized because it is not accessible, or it is unsafe or unacceptable to use, or it is being created but not yet built, or it simply does not exist, simulation is employed. (Ref wiki Simulation)

Simulation technique is widely used in Academia and Business. Laboratory experiments have traditionally been used to teach technology-based courses utilizing a hands-on approach. With the shrinking of integrated circuits, building a PC board, or assembling surface mount chips in a lab environment is getting increasingly challenging. Because of the shortcomings of the hands-on approach, professors and teachers have begun to substitute simulation for hands-on in technology-based lab courses.

Simulation-based training is expected to bridge the gap between the learning environment and the "real" environment, allowing for instruction of "real world" scenarios that are difficult to replicate in a hands-on lab setting. No doubt hands on experience is very important but through computer simulation the students can experience real life situations under a safe environment by trial and error method.

Simulation models help industries to develop the products faster and also to save money on physical testing production cost. It is essential for the students to be familiar with Simulation to become industry ready.

Hence it is a matter of academic interest and in the academic front various studies have been conducted to evaluate the effect of simulation on students learning starting with school education in different subject areas.

Work done on Simulation based Pedagogy:

Problem-oriented simulations, according to (Veenman et al 1994) assist students acquire higher-order thinking methods and increase their cognitive capacities in the areas of recall, problem-solving, and creativity. Students can experiment interactively with the fundamental theories and applications of electronic devices using computer-based simulation tools. It allows them the ability to try out numerous possibilities and evaluate their ideas for accuracy virtually instantaneously because it provides instant and trustworthy feedback. Lab students frequently assume that lab equipment is not always accurate and dependable, and they frequently associate their design make the error to experimental error in such a case simulation can help the students' attention to their design part.

Although the value of hands-on laboratories in the technology curriculum cannot be ruled out (Garcia, 1995) claims that computer simulations have significant advantages over laboratory activities. First, employing computer simulations in the classroom appears to have significant pedagogical benefits. Second, lab equipment is often more expensive to buy, maintain, and update than computer hardware and software. In addition, pupils' physical safety is not a worry in the simulated learning environment.

The research findings of (M T Taher,et al 2017) through his case study method reveals

that simulation is ineffective in boosting student learning on its own but When simulation is followed with hands-on activity and feedback mechanisms, it becomes more successful. The report also includes ideas for using simulation-based, hands-on, and feedback-based teaching approaches to improve student learning.

With the rapid advancement of technology and programming languages simulation has evolved into a sophisticated tool that will reflect real world situations with more accuracy. (Martin and McEvoy 2003)

According to Alsaadani and Bleil De Souza (2019), universities are using simulation to teach architects about building performance.

Overall, the analysis indicates a rising interest in the potential of Simulation education as a tool for training managers and engineers from many industries and businesses, apart from teaching STEM courses to students. A study conducted by in Mavinkurve and Patil (2016) in the usage of electrical circuit simulator in engineering courses revealed that, the simulator helped the students to improve their assessment ratings.

McHaney (2018) presented optimal practices for using simulation Education in cloud computing and big data courses. In case of big data courses students use simulation to produce big data sets for analysis. According to (Grasas et al. 2013, Ceberio et al. 2016) simulation can be an apt resource for many online courses due to its capability of supporting virtual laboratories.

OBJECTIVE OF THE STUDY

The purpose of the study was to explore the impact of Simulation on the learning outcome of students in different streams of STEM field, feedback of students and Teachers on their experiences of using computer Simulation as a pedagogy in theory and Practicum in class room.

The Study Attempts to Answer the Following Questions

- Is there any significant difference in the performance of students before and after introducing computer simulation?
- Is there any significant difference between the performance of the students gender wise before and after introducing computer simulation?
- Comparison of students and teacher's feedback on simulation as a pedagogy

SCOPE OF THE STUDY

The current study focuses on the responses of the Degree college students of B.Sc. Physics, B.Sc. (IT), Engineering Students of B.E in three different Institutions in Mumbai and the teachers in the above streams.

METHODOLOGY

Teachers were asked to introduce a particular topic in their respective streams in conventional method first and were asked to take the evaluation of the students on the understanding of the topic. Later the teachers were asked to give an assignment on the same topic to be performed by computer simulation, after the completion of the assignment the teachers were asked to evaluate the students on the same which is termed as post-test and the performance was compared.

This is survey-based research. The data was collected from 3 of the top 10 Colleges in Mumbai. The data was collected through of Google form both from students and teachers after giving the background of the study. Out of the three Institutions participated in the survey, two are Degree Colleges and one is an Engineering College. Two separate Google forms were created one for students and the other for teachers. In all 139 students and 30 teachers participated in the survey.

Students form contained some basic information about name, age, Programme of study, Institution, specialization/major, the pedagogies used currently in their institutions, their feedback on Simulation technology on various aspects, pre and post- test evaluation.

Teachers Google form contained the information pertaining to the number of years of teaching experience, their perception and experience on student learning when simulation is used as a pedagogy, their opinion about the feedback on the financial burden to the institution. The students' data was analyzed overall combining all the three colleges put together and also individually stream wise B.Sc. (Physics), B.Sc. (IT), B.E

RESEARCH STATEMENTS

The study was based on the following Research Statements:

- Is there any significant difference in the performance of the students in pre and post test?
- Is there any significant difference in the performance of the students in pre and post test gender wise?
- Is there any difference in the perception of students and Teachers feedback on computer Simulation as pedagogy?

RESEARCH HYPOTHESIS

- **$H_0$1:** There is no significant difference in the pre test and post test scores.
- **$H_0$2:** There is no significant difference in the pre test and post test scores gender wise
- **H_o3:** There is no significant difference in the pre test and post test scores of B.Sc. Physics students.
- **$H_0$4:** There is no significant difference in the pre test and post test scores of B.Sc. (IT) students.
- **H_o5:** There is no significant difference in the pre test and post test scores of B.E Engineering students.

DATA COLLECTION

Two separate Google forms were created one for students and the second one for teachers. The link of the Google forms were sent to the three institutions participated in the survey. Both the forms contained the background of the study. In all 139 students and 30 teachers participated in the survey. The collected data was analyzed through SPSS software.

DATA ANALYSIS

The following table gives the stream wise and gender wise distribution of students participated in the survey.

Table 1

College * Gender Cross Tabulation					
Count					
		Gender		Total	Percentage
		Male	Female		
College1	EngineeringB.E	37	20	57	41.01%
College 2	B.Sc. (IT)	22	23	45	32.37%
College 3	B.Sc. (Physics)	22	15	37	26.62%
Total		**81**	**58**	**139**	**100%**

Impact of computer Simulation on the learning outcome of the students overall in STEM subjects irrespective of the stream was tested through the pre-test and post-test scores of the students overall through the following research hypothesis. Paired sample t test was used at 5 % level of significance.

Research Hypothesis: 1

- Ho: There is no significant difference in the pre- test and post- test scores of the students.
- H_1: There is significant difference in the pre- test and post- test scores of the students.

The data was analyzed through SPSS and the following output is obtained.

Table 2

Paired Samples Statistics					
		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Pre Test Scores	71.9413	139	14.58719	1.23727
	Post Test Score	80.6962	139	14.50015	1.22989

Table 3

Paired Samples Correlations				
		N	Correlation	Sig.
Pair 1	Pre Test Scores & Post Test Score	139	.544	.000

Table 4

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Pre Test Scores - Post Test Score	-8.75489	13.89389	1.17846	-11.08507	-6.42471	-7.429	138	.000

Table 2 shows that the Mean of pre-test score is 71.94 and that of post-test score is 80.69. Table 4 shows the difference in the mean is 8.75 and the p value is 0.000 < 0.05, implying that the difference is significant. Hence we reject the null hypothesis. The conclusion is Simulation technology has a positive Impact on the students learning outcome.

Research Hypothesis 2

To test the impact of Simulation in the learning outcome gender wise

- **Ho:** There is no significant difference in the pre- test and post- test scores of the students' genderwise.
- **H_1:** There is significant difference in the pre- test and post- test scores of the students' gender wise.

The SPSS outputs are given in Table 5, Table 6 and Table 7.

Table 5

Paired Samples Statistics						
Gender			Mean	N	Std. Deviation	Std. Error Mean
Male	Pair 1	Pre Test Scores	71.3827	81	13.10207	1.45579
		Post Test Score	79.8519	81	13.68769	1.52085
Female	Pair 1	Pre Test Scores	72.7214	58	16.52791	2.17022
		Post Test Score	81.8753	58	15.60953	2.04963

Table 6

Paired Samples Correlations					
Gender			N	Correlation	Sig.
Male	Pair 1	Pre Test Scores & Post Test Score	81	.673	.000
Female	Pair 1	Pre Test Scores & Post Test Score	58	.416	.001

Table 7

Paired Samples Test										
Gender			Paired Differences					t	df	Sig. (2-tailed)
			Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
						Lower	Upper			
Male	Pair 1	Pre Test Scores - Post Test Score	-8.46914	10.83869	1.20430	-10.86577	-6.07251	-7.032	80	.000
Female	Pair 1	Pre Test Scores - Post Test Score	-9.15397	17.38396	2.28263	-13.72485	-4.58309	-4.010	57	.000

Table 7 shows both in Male and female students the difference in the mean scores of post and pre test are 8.47, 9.13 respectively. This difference is significant as the p value is 0.000 <.0.05.in each case.The conclusion is , there is significant difference in the learning outcome gender wise.

To find out whether there is significant difference in the learning out of the students in different streams of STEM subjects namely Physics, Technology and Engineering the analysis was done stream wise with the following research hypothesis.

Research Hypothesis 3

- **Ho:** There is no significant difference in the learning outcome of Engineeringstudents
- **H1:** There is no significant difference in the learning outcome of Engineeringstudents

Research Hypothesis 4

- **Ho:** There is no significant difference in the learning outcome of B.Sc. (IT) students
- H1: There is no significant difference in the learning outcome of Engineering students

Research Hypothesis 5

- **Ho:** There is no significant difference in the learning outcome of Physics students
- H1: There is no significant difference in the learning outcome of Physics students

The stream wise analysis is represented in the following SPSS output Table 8, Table 9, Table 10

Table 8

Paired Samples Statistics						
College			**Mean**	**N**	**Std. Deviation**	**Std. Error Mean**
Engineering College	Pair 1	Pre Test Scores	73.4737	57	13.91826	1.84352
		Post Test Score	83.5263	57	12.78826	1.69385
Degree College B.Sc. (IT)	Pair 1	Pre Test Scores	74.7742	45	10.86031	1.61896
		Post Test Score	82.2171	45	13.67334	2.03830
Degree College B.Sc. (Physics)	Pair 1	Pre Test Scores	66.1351	37	17.93842	2.94906
		Post Test Score	74.4865	37	16.36667	2.69066

Table 9

Paired Samples Correlations					
College			**N**	**Correlation**	**Sig.**
Engineering College	Pair 1	Pre Test Scores & Post Test Score	57	.759	.000
Degree College B.Sc. (IT)	Pair 1	Pre Test Scores & Post Test Score	45	.285	.058
Degree College B.Sc. (Physics)	Pair 1	Pre Test Scores & Post Test Score	37	.442	.006

Table 10

Paired Samples Test										
College			Paired Differences					t	df	Sig. (2-Tailed)
			Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
						Lower	Upper			
Engineering College	Pair 1	Pre Test Scores - Post Test Score	-10.05263	9.33966	1.23707	-12.53078	-7.57449	-8.126	56	.000
Degree College B.Sc. (IT)	Pair 1	Pre Test Scores - Post Test Score	-7.44289	14.84219	2.21254	-11.90198	-2.98380	-3.364	44	.002
Degree College B.Sc. (Physics)	Pair 1	Pre Test Scores - Post Test Score	-8.35135	18.16776	2.98676	-14.40878	-2.29392	-2.796	36	.008

Table 10 shows that the p value is 0.000 for Engineering, 0.002 for B.Sc. (IT), 0.008 for B.Sc. (Physics) each one is less than 0.05 hence we reject the null hypothesis in each case and conclude that the difference in the mean scores of pre and post test is significant and simulation has a positive impact on learning when analyzed stream wise also.

Feedback of Students of their Experience using Simulation as Pedagogy

Table 11 shows the feedback of students on Likert scale for various statements mentioned in the table.

Table 11

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I could perform my test better after doing experiments with Simulation	2%	9%	37%	41%	12%
In industries Simulation is very useful	0%	2%	26%	48%	24%
Simulation helps to rectify the errors by trial and error method	0%	2%	19%	55%	24%
Simulation must be part of pedagogy STEM Education	0%	3%	27%	53%	17%
Simulation helps in understanding the concept better	3%	12%	36%	35%	14%

The feedback of students on simulation based learning is represented diagrammatically in figure1 and the same is tabulated in Table 12.

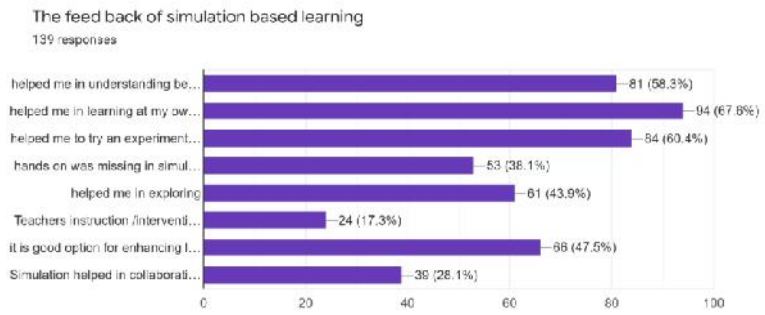

Figure 1

Table 12

Helped me in understanding better	58%
Helped in learning at my own pace	68%
Helped me to try an experiment a number of times with variations	60%
Hands on was missing	38%
Helped me exploring	44%
Teachers instruction and intervention was not possible	17%
It is a good option for enhancing learning	48%
Helped me in collaborative learning	28%

From Table11 and Table12, it is very clear that the students have a positive experience on Simulation based learning, though 38% (ref Table 12) of the students felt hands on was missing. The students were also asked about how much they were confident about learning through Direct Instruction, Simulation, and a combination of both. 86% of the students preferred a combination of both,7% felt through Direst Instruction and an equal percentage felt through simulation.

ANALYSIS OF TEACHERS FEEDBACK

Data was collected through Google form from 30 teachers of the three Institutions from where the students participated in the survey. The Table 13 details the gender and Teaching experience.

Table 13

Gender		**Teaching Experience**		
Male	**Female**	**< 5 years**	**5-10 Years**	**10 Years and Above**
63%	37%	3%	27%	70%

Teachers Feedback on use of Simulation is given in Table 14

Table 14

	Not at all	**Some times**	**More Frequently**	**Always**
Have you been using simulation during face to face Lectures?	10%	57%	27%	6%
During on line lectures how frequently you have been using Simulation?	3%	43%	27%	27%

The Table14 indicates that during online lectures now, the teachers have started using simulation more frequently and always as compared to Face to Face lectures.

To The Descriptive Question

What is your overall experience of using Simulation as a pedagogy with respect to students understanding and performing the experiments or any given project?

The teachers have responded positively and felt good and excellent. The extract of a few responses are given belo was stated by them:

Its more comfortable for few subjects but not for all Simulation keep student engage and also help to understand the result with justification

Helps immensely to make a concept clearer, Students are able to experiment and evaluate circuit functioning, before actual implementation. Students shall be better prepared for practical sessions.

Students are able to change various parameter values and analyze the electronic circuits or devices in a better way. Simulations strengthen the concepts and develop the importance and the significance of magnitude changes in parameters.

It is a good option especially in electronics as it gives an idea to the students about the circuit without the risk of the circuits being burnt due to wrong inputs. It can definitely be suggested for testing and then one can implement on the actual circuit after testing

Do you feel Simulation enhance the learning outcome of students in class? Why or Why not? Please give a brief response?

The teachers' responses for the above question were yes some of the reasons given by the teachers are reproduced below as stated by them:

Depending on the Topic

Yes, it helps student to apply new techniques and helps to meet the requirement of the industry.

Yes, Simulation will give better experience to visualize the concept, which will lead to actual deployment

Simulation tools can help students experiment, experience and learn, without requiring expensive resources. They very easily fill in for the absence of resources at learner's disposal. They are necessary prerequisites before learner actually performs the practical. So yes they definitely help improve outcomes in a class.

Yes. Using simulation students will visualize (animations) the concept.

Yes 75%. But with simulation hardware knowledge is also must

Yes. but teacher first and then simulator

Yes, it will enhance because students have freedom to change various parameters and they are "learning by doing"

Yes. For my subjects, simulation allows them the flexibility to check different options while working on a code. Also it gives them confidence to handle the physical circuits as they have some experience from simulation

When the teachers were asked about the additional cost to include simulation in regular pedagogy the response was many open source software are available and the teachers are using them. In certain advanced cases the free sources are not available and the cost is high

The Table 15 shows the comparison of students and teachers Response on certain aspects based on their perception and experience .

Table 15

	Agree and Strongly Agree Teachers	Agree and Strongly Agree Students
Simulation based learning helps students to understand the concept better	97%	58%
Simulation based learning helps students to learn at their own pace	93%	68%
Simulation based learning helps students to learn by trial and error	93%	79%
Simulation based learning should become part of STEM Teaching learning pedagogy	87%	70%

Table 15 indicates that the perception and experience of the teachers is higher than that of students on Simulation based learning. It may be due to the fact that the now only the students are experiencing simulation during online lectures and may require more exposure in due course.

80% of the teachers responded that Simulation based learning has become a widely used pedagogy after the outbreak of COVID 19.

CONCLUSIONS

The above study revealed that from the study of pre-test and post -test scores there is significant difference in the learning outcome of students when the analysis was done overall and also stream wise. Learning outcome is also significant when analyzed gender wise.

Before the outbreak of Covid 19 almost all the lectures and Practical were conducted face to face and students had less exposure to online lab and Simulation. This aspect is inferred from the teacher's response which shows only 6% have been always using Simulation during face to face lectures. Now the percentage has increased to 27%

RECOMMENDATIONS

Since the students have a positive perception about the benefits of simulation-based learning and also 86% of them strongly feel a combination of direct instruction and Simulation is preferred it is recommended that Simulation based learning should be part of regular curriculum to enhance and Innovate STEM learning. The study concentrated on Physics, Technology and Engineering fields. A similar study can be carried out for other STEM subjects which will enable the policy makers to design a curriculum with industrial experts and use of technology enhanced methods like Simulation to bridge the gap between Industry and Academia and make the students directly employable by enhancing their skill sets make them not only Industry ready but also make them innovators rather than users.

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